

***Spitzer* 4.5 μm Luminosity-Metallicity and Mass-Metallicity Relations for Nearby Dwarf Irregular Galaxies**

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Summary. For a sample of 25 dwarf irregular galaxies with distances $D \lesssim 5$ Mpc and measured oxygen abundances, we present results derived from galaxy luminosities at 4.5 μm and stellar masses from near-infrared imaging with IRAC on the *Spitzer Space Telescope*. We have constructed the appropriate luminosity-metallicity (L - Z) and mass-metallicity (M - Z) relations, and compared these relations with their corresponding relations from the Sloan Digital Sky Survey (SDSS). We obtain the following results. 1. The dispersion in the near-infrared L - Z relation is reduced with respect to the dispersion in the optical L - Z relation, which agrees with expectations for reduced variations of stellar mass-to-light ratios at longer wavelengths compared to optical wavelengths. 2. The dispersion in the optical L - Z relation is similar over approximately 11 mag in optical luminosity. 3. With our constructed M - Z relation, we have extended the SDSS M - Z relation to lower masses by about 2.5 dex in stellar mass. 4. The dispersion in the M - Z relation appears to be comparable over a range of 5.5 dex in stellar mass.

1 Near-Infrared Luminosity-Metallicity Relation

The luminosity-metallicity (L - Z) relation for nearby dwarf irregular galaxies has been studied traditionally at optical wavelengths (e.g., [7, 11, 9, 5, 13]). However, the dispersion in the optical L - Z relation is affected by variations in stellar mass-to-light ratios, which are caused by variations in the current star formation rate among galaxies. To minimize the effects of these variations, we determine the L - Z relation at near-infrared wavelengths where stellar populations dominate the emission. The sensitivity of the *Spitzer Space Telescope* provides an excellent opportunity to observe the total near-infrared emission from the stellar populations in nearby dwarf galaxies. The present results are based on observations taken with IRAC in channel 2 (4.5 μm); we assume that the contribution from warm and/or small dust grains at 8 μm is negligible in dwarf galaxies [3].

We have measured 4.5 μm luminosities for 25 galaxies taken from GTO program 128 (P.I. R. D. Gehrz) and the *Spitzer* archive. Located within the

Local Group and other nearby groups, these galaxies have measured distances ($D \lesssim 5$ Mpc) and oxygen abundances. The optical and near-infrared L - Z relations [6] are plotted in Figs. 1a and b, respectively. The dispersion in the L - Z relation is reduced at near-infrared wavelengths compared to the dispersion in the optical relation. By comparison with the optical L - Z relation for more massive galaxies [12] from the Sloan Digital Sky Survey (SDSS), it appears that the dispersion in the optical L - Z relation is similar ($\simeq 0.16$ dex) over 11 magnitudes in optical luminosity.

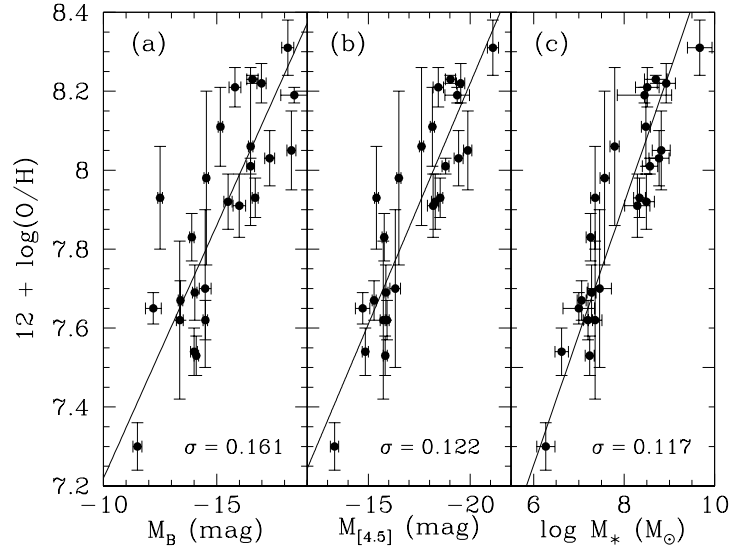


Fig. 1. Panel (a): optical (B) luminosity-metallicity relation with dispersion $\sigma = 0.16$ dex. Panel (b): near-infrared ($4.5 \mu\text{m}$) luminosity-metallicity relation with dispersion $\sigma = 0.12$ dex. Panel (c): stellar mass-metallicity relation with dispersion $\sigma = 0.12$ dex. In each panel, the solid line represents a linear least-squares fit to the data.

2 Stellar Mass-Metallicity Relation

With measured luminosities at $4.5 \mu\text{m}$, we have derived stellar masses for our sample of dwarf irregular galaxies. We have used the models from Bell & de Jong [1] to determine stellar mass-to-light ratios as functions of $B-K$ color, and we have applied a correction for nonzero $K-[4.5]$ color in late-type dwarf galaxies (e.g., [8]). We have also adjusted the derived stellar masses to the Kroupa [4] stellar initial mass function; additional details of the derivation are provided in [6].

The stellar mass-metallicity (M - Z) relation [6] is shown in Fig. 1c. The M - Z relations for dwarf galaxies and for massive galaxies from the SDSS are shown in Fig. 2a. With the present sample of dwarf galaxies, we have extended the SDSS M - Z relation to lower stellar mass by 2.5 decades. We find that the dispersion in the M - Z relation is comparable (≈ 0.10 – 0.12 dex) over a range of 5.5 decades in stellar mass, although we have not performed a homogeneous treatment of gas-phase metallicities and stellar masses for the SDSS sample; see [6] and [12] for details.

We have plotted the effective yield as a function of total baryonic mass in Fig. 2b. The simple closed-box model of chemical evolution (see, e.g., [10]) predicts that the effective yield is equal to the true yield for all masses. However, that the effective yield decreases at lower baryonic mass is commonly interpreted as a signature of either outflow or dilution from the infall of metal-poor gas. We find that the present sample of dwarf galaxies exhibits a much larger variation in the effective yield at a given total baryonic mass. The large variation in the effective yield is difficult to explain if galaxy outflows are dominant in low-mass dwarf galaxies; see [12] for a countering view.

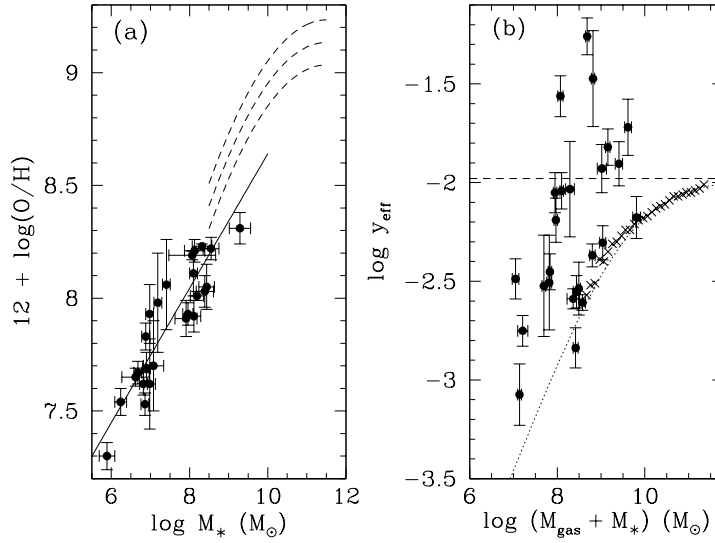


Fig. 2. Panel (a): Stellar mass-metallicity relation over 5.5 dex in stellar mass. The filled circles and solid line represent the present sample of dwarfs and the best fit, respectively. The relation from the SDSS and the ~ 0.10 dex curves from [12] are shown as dashed lines. Panel (b): Effective yield versus total baryonic mass. The crosses represent the median of the SDSS data in mass bins of 0.1 dex [12]. An empirical fit is shown as a dotted line, and the asymptotic yield ($y_{\text{eff}} = 0.0104$) is shown as a horizontal dashed line.

3 Stellar Iron Abundances vs. Near-Infrared Luminosity

Stellar masses for our sample of dwarf galaxies have been derived from near-infrared luminosities under the assumption that the emission is dominated by the populations of older stars. Iron abundances are a good tracer of the chemical evolution for these stars integrated over the entire history of past star formation. We have constructed an L – Z relation using photometric stellar iron abundances from the literature to examine if the correlation is comparable to the relation constructed using gas-phase metallicities. The iron abundance-luminosity relation is shown in Fig. 3. Unfortunately, the photometric iron abundances have large uncertainties or spreads. Nevertheless, there appears to be a trend between the mean photometric iron stellar abundance and the measured galaxy luminosity at $4.5\ \mu\text{m}$ in the same sense as that found in Fig. 1.

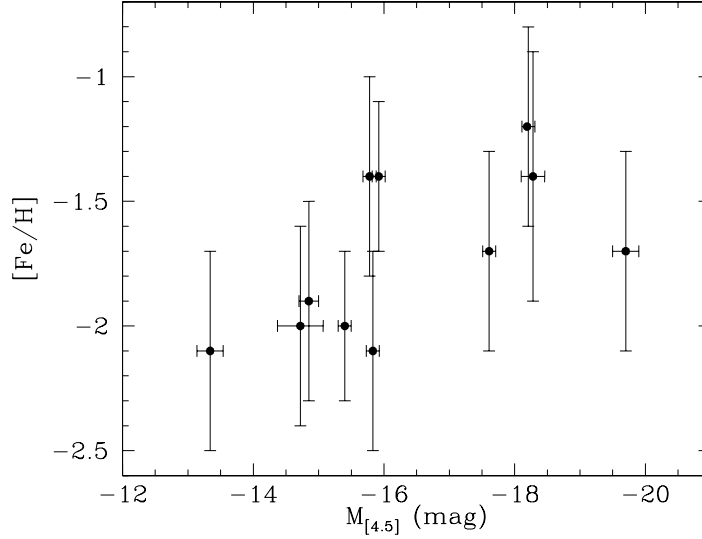


Fig. 3. Stellar photometric iron abundances vs. absolute magnitude at $4.5\ \mu\text{m}$. The iron abundances were taken from [2].

4 Final Remarks

The challenge is explaining the relatively uniform scatter in both the L – Z and M – Z relations. Additional near-infrared imaging and spectroscopy for a large number of dwarf galaxies within the Local Volume can test whether the

scatter in the $L-Z$ and $M-Z$ relations holds over a large range in luminosity and mass. The growing interest in determining the redshift-evolution of the $L-Z$ and $M-Z$ relations provides good impetus to exploring galaxy formation models that incorporate varying degrees of galaxy outflows and can predict the slope and the scatter in the $L-Z$ and $M-Z$ relations over large dynamic range.

References

1. E. F. Bell, & R. S. de Jong: ApJ **550**, 212 (2001).
2. E. K. Grebel, J. S. Gallagher, & D. Harbeck: AJ **125**, 1926 (2003).
3. D. C. Jackson, J. M. Cannon, E. D. Skillman, H. Lee, R. D. Gehrz, C. E. Woodward, & E. Polonski: ApJ, submitted (2006).
4. P. Kroupa: MNRAS **322**, 231 (2001).
5. H. Lee, M. L. McCall, R. L. Kingsburgh, R. Ross, & C. C. Stevenson: ApJ **125**, 146 (2003).
6. H. Lee, E. D. Skillman, J. M. Cannon, D. C. Jackson, R. D. Gehrz, E. F. Polonski, & C. E. Woodward: ApJ, submitted (2006).
7. J. Lequeux, M. Peimbert, J. F. Rayo, A. Serrano, & S. Torres-Peimbert: A&A **80**, 155 (1979).
8. M. A. Pahre, M. L. N. Ashby, G. G. Fazio, & S. P. Willner: ApJS **154**, 235 (2004).
9. M. Richer & M. McCall: ApJ **445**, 642 (1995).
10. L. Searle, & W. L. W. Sargent: ApJ **173**, 25 (1972)
11. E. Skillman, R. Kennicutt, & P. Hodge: ApJ **347**, 875 (1989)
12. C. Tremonti et al: ApJ **613**, 898 (2004).
13. L. van Zee, E. D. Skillman, & M. Haynes: ApJ **637**, 269 (2006)